Record 8

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	2 p. Recent laser cleaning has shown effective particulate removal from a surface using laser irradiation together with liquid-film deposition. This is easily done on a "robust" surface (e.g., Si wafer) which withstands relatively high laser fluence. For delicate surface (e.g., thin carbon), we show that laser damage is greatly reduced or eliminated by droplet condensation on the particulates together with large incidence-angle irradiation. With the rapid advance in miniaturization, resolution, and performance in high-technology, the demand for effective cleaning of even tiny submicron particles without damaging delicate parts becomes more and more critical. The inadequacies of existing cleaning techniques is well summarized in a recent article (1); these techniques including liquid rinses, ultrasound, plasmas, electrostatics, gas jets, and other conventional cleaning techniques are all regarded as ineffective for submicron particle removal. To remedy this situation, various techniques of "laser cleaning" have recently been demonstrated, e.g., "dry laser cleaning" (2), "wet laser cleaning" with continuous liquid-film enhancement (3), and "wet laser cleaning" with pulsed liquid-film enhancement (4). However, these previous investigations required relatively large laser fluence, e.g., about 0.3, 30, and 0.2 J/cm2 in (2, 3 and 4), respectively. While these work well for relatively "robust" surface, delicate surface could be damaged by the laser pulses. For example, in our attempt to perform liquid-film enhanced laser cleaning of a carbon-coated ceramic surface, we observed that even a fluence of 100 mJ/cm2 would cause removal of the thin a-carbon coating. This situation is observed for a carbon-coated ceramic surface being cleaned by several pulses from a KrF laser at a fluence of 120 mJ/cm2 at normal incidence with pulsed water enhancement (4); while particles are definitely removed, the carbon coating at the surface is also completely removed too. When the fluence is reduced to 100 mJ/cm2, the carbon coating at the surface is still partially removed. At lower fluence, cleaning becomes ineffective. Hence, this straightforward laser cleaning cannot be simply applied to clean delicate parts like the magnetic heads.

Text of Submission	The present invention shows how to overcome the difficulty above for laser cleaning of minute particles from such delicate surfaces that can be damaged by excessive laser fluence. We discovered that when small amounts of saturated or supersaturated vapor is blown onto the particle-contaminated carbon-coated surface, the vapor condenses as droplets mainly on the particles, but not on the clean areas. We further show that if this surface with tiny liquid droplets is exposed to the laser irradiation of a suitable fluence and large incidence angle, the particles can be effectively removed without any damage to the carbon coating. The reasons why the combination of "droplet condensation" together with "large incidence angle" work so well may be the following: The droplets present a large cross-section to intercept the slanted beam, while the clean area sees a reduced laser fluence (reduced by the cosine of the angle of incidence). The heat deposition at the clean area is further reduced due to the large reflectivity at large incidence angle. The refraction of the incident laser light at the liquid droplet causes the laser pulse to deflect and concentrate towards the particle/substrate interface, causing fast heating at this interface and explosive vaporization under the particle and hence particle ejection. Summary We invented a pulsed-laser surface-cleaning technique to effectively remove particles from a delicate surface without damaging it. This technique involves pulsed deposition of liquid droplets onto the particulates on the surface together with pulsed laser irradiation at large incidence angle (typically larger than 45o). This invention has enabled us to demonstrate the important task of laser **cleaning** of magnetic heads without removing any of the carbon coating. References (1) P. Ross, "Dust Busters: Laser wipe submicron motes from silicon wafers," Scientific American 262, 6, 86-88 (June 1990). (2) W. Zapka and A. C. Tam, "Particulate removal from a surface by excimer laser irradiation," CLEO 1990 Technical Digest Series 7, 227-228 (1990). (3) K. Imen, S. J. Lee and S. D. Allen, "Laser assisted micron scale particulate removal," CLEO Technical Digest Series 7, 228-229 (1990), and Applied Physics Letters 58, 203 (January 1991). (4) W. Zapka, W. Ziemlich and A. C. Tam, "Efficient laser removal of 0.2 mm gold particles from a surface," Applied Physics Letters 58, 2217 (May 1991).
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